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The Role of Micro Wind Generation in Ireland's Energy Future

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***Abstract*-This paper defines the current position for micro-generation, with particular reference to the potential for micro-wind units, in the Irish electricity supply system. A network model is developed using the *Distflow* method of load flow analysis and is applied to consider the appropriate level of micro-generation penetration.**

I. INTRODUCTION

Small Scale Embedded Generation (SSEG), including micro-wind, can possibly assist in the achievement of the commitment to supply 13.2% of the electrical demand in Ireland from renewable energy sources by 2010 [1]. During the period 1992-2002, electricity demand in Ireland was increasing annually at a rate of 5.5% [2]. More recently, the growth in electricity demand has been about 4%. If this trend continues, demand for electricity will have increased by 79% in 15 years. A Sustainable Energy Ireland Report (SEI) [3] suggests that electricity demand by final customers in Ireland grew by 118% (5% average annual growth) over the period 1990 to 2006.

Research has shown that micro-generation can provide significant value in terms of avoidance of load related capital expenditure as well as an associated offset of energy costs [4,5].

Micro-generation in Ireland can be considered at its initial stages of development. Micro-generation is defined as technology that can deliver 25 A at 230 V or 16 A at 400V. The Electricity Supply Board (ESB, PES in Ireland) and more specifically ESB Networks (DSO) published technical guidelines [6] on the connection of micro-generation. The Commission for Energy Regulation (CER) – the regulator of the electricity and natural gas sectors in Ireland - subsequently issued a direction on the logistics of grid connection. However, there are no payments for spill and at present no plans for a feed-in tariff or other incentives.

This paper initially provides an overview to the Irish policy underpinning the development of the sector. European benchmarks are offered with a more comprehensive comparison with the UK position. A representation of the Irish Distribution Network (Fig. 1) has been developed which utilises MATLAB© to derive the Load Flow and subsequent voltage profile for a range of load/generation scenarios. The technique employed is *Distflow* and the model, technique and analysis are described.

II. MICRO-GENERATION IN IRELAND

In November of 2007, CER issued its response and decision on a consultation into the 'Arrangements for Micro-generation' [7], which was instigated in recognition of the increasing number of smaller commercial generator units connecting to the electricity network. The outcomes included:

- Endorsement of EN50438 as the technical standards appropriate to the technologies
- Direction that the connection process would be 'Inform, Consent and Fit' where customers are obliged to inform the DSO of the connection of a micro-generator with the DSO maintaining a list or register of type approved micro-generation units
- An initial limit on the installation of micro-generation at 40% of the local transformer capacity.
- No provision for the arrangement of spill payment or for a feed-in tariff but with the advent of smart metering, there might be a means to address this situation long term.

It is accepted that there would be costs associated with increased penetration of SSEG. At the same time, the impact of a penetration level up to 40% from a network performance perspective merits consideration. However, the proposal not to consider the option of remuneration for spill may prevent the large scale uptake of these technologies. There is an obligation on the part of the DSO to ensure open access to networks in conjunction with a non-discriminatory charging policy on the issue of embedded generation.

In conjunction with this consultation and in light of the EU Directive on energy end use efficiency and energy service [1], CER also sought responses on a consultation pertaining to Demand Side Management and Smart Metering [8]. The consultation posed questions relating to the most efficient means of influencing customers' use of electricity and how the tariff structures should be constructed to achieve such a goal. The consultation further suggested that smart metering facilitate the means to account for excess electricity spilled on to the network but would 'further the debate' on the value of electricity exported from the micro-generator on to the system.

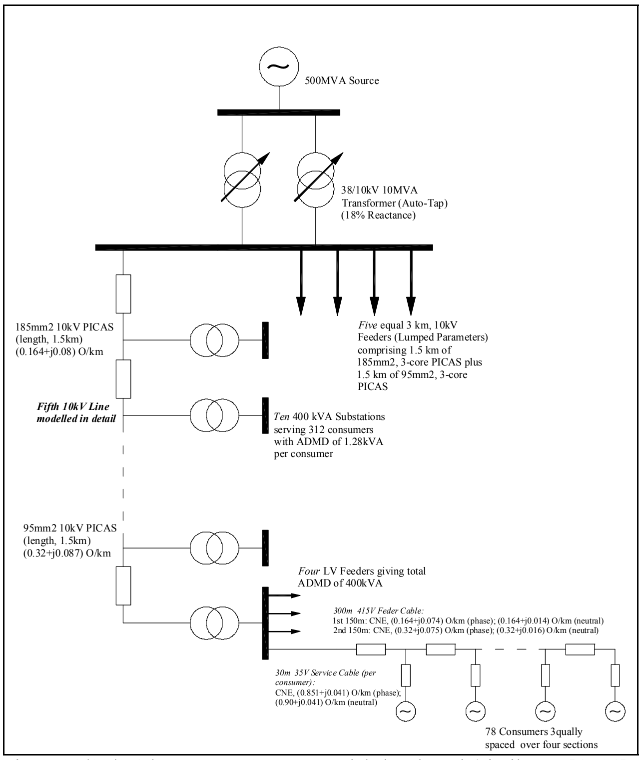

Fig 1. 38/10/0.4 kV Power System Model developed (similar to [4, 14] incorporating the *Distflow* Load Flow Technique

The residential sector consumes a significant amount of energy in Ireland, accounting for 31.2% of Ireland's primary energy consumption in 2006 [3]. However, even with increased prices for energy, it is not clear that that consumers are engaging in practices leading to reduction in consumption. Load reduction is proportional to customer response and is dependent on real time pricing feedback and reduction in peak demand is achieved from customers responding to time of use tariffs.

A change in consumer behaviour and/or complementary measures (e.g. consumer awareness campaigns) to deliver a reduction in quantity or timing of load is required. Innovative metering would facilitate a shift in peak demand usage but more needs to be done to stimulate customer focus.

The current standard for the connection of micro-generation in Ireland does not warrant a mechanism for the sale and export of excess electricity from micro-generation. Indeed, EN50438, the European Standard (due for final voting in 2008) dealing with the technical aspects such as power quality, safety and interface protection rather than the mode of metering.

Ofgem in the UK released a consultation document in February 2006 [9] in which a number of questions regarding the adoption of 'innovative metering' as well as associated implementation issues were raised. The position within the UK market is one where metering is decoupled from the DNO and there is competition in the domestic metering market. The decision was not to mandate the introduction of smart meters but to instead rely on the competitive nature of the market to produce commercial incentives orientating consumers to alter their consumption patterns.

In the Irish context, there is currently no competition in metering services. Clearly it is customer response rather than the meter technology itself which delivers any savings and a time of use tariff structure will provide such an incentive.

Sustainable Energy Ireland (SEI) administers a grant scheme, 'Greener Homes Scheme' (Phase II) providing assistance to homeowners who intend to purchase a renewable energy heating scheme for either new or existing homes. In its current form, the grant scheme does not support electricity generation. This is on the basis that technologies such as residential wind turbines currently offer a lower cost per CO_2 abatement than the technologies being afforded grant consideration (solar heating, heat pumps, wood chip/pellet stoves and wood chip/pellet boilers) and also that there are significant technical and regulatory barriers to be overcome. However, as these barriers are overcome and with maturity in the generation technologies, further consideration into participation of such technologies on the grant scheme(s) could be offered.

In relation to micro-generation, there is no current estimates pertaining to the amount of micro-generation being installed in Ireland and the amount of electricity provided from this source of power, but if such technologies are to be encouraged, a form of smart metering and the means to accurately ascertain the import/export patterns is of paramount importance. An Energy Savings Trust study [10] suggests that 30-40% of the UK's electricity demands could be met through micro-generation technologies by 2050. In that context, an opportunity now presents itself to encourage the adoption of said technologies in the guise of how metering implementation choice could facilitate the increased penetration of micro-generation.

III. Micro Wind Generation

Wind turbines extract kinetic energy from moving air, converting it into mechanical energy via the turbine rotor and then into electrical energy through the generator. The kinetic energy of the wind, flowing through the turbine rotor is described by P_{wind} as:

$$P_{wind} = \frac{1}{2}\rho_{air} A_{blades} u^3 \qquad (3)$$

where

ρ_{air}	- the mass density of air;
A_{rotor}	- the propeller area;
u	- the wind speed.

Micro wind generators can be either horizontal axis (HAWT) or vertical axis (VAWT) with ratings from 0.3 – 6kW. Their associated characteristics include blade diameter, cut-in speed, rated speed, rated power and output at rated speed. The two defining aspects of a wind turbines performance are the blade sweep area and the associated power curve for the specific technologies. The blade sweep area defines the amount of power that can be captured from the available wind on site whilst the power curve illustrates the turbines performance against varying wind speeds. The performance coefficient, C_p , of the turbine defines how much power is captured and turned into rotational energy to subsequently generate electricity.

The mechanical energy P_{mech} that is taken by the wind is equal to:

$$P_{mech} = \frac{1}{2} . c_p . \rho_{air} . A_{blades} . (v_{wind})^3 \qquad (2)$$

Where:

- P_{mech} = Mechanical output power of thennnnnnn turbine [W]
- c_p = Performance coefficient of the turbine – i.e. the fraction of the kinetic energy of the air captured as rotational energy by the turbine blades
- ρ_{air} = Air density [$kg.m^{-3}$]
- A_{blades} = Turbine swept area [m^2]
- v_{wind} = wind speed [$m.s^{-1}$]

A brief survey of some of the available technologies was undertaken and the results of this suggested that performance coefficients can vary from 0.18 to 0.41.

Wind as a resource is the fastest growing renewable source globally increasing by 28% (21GW) in 2007 from 2006 [11]. In the EU, there have been annual increases and the European Wind Energy Association (EWEA) estimates that installed wind power capacity in the EU will reach 80 GW in 2010 and 180 GW by 2020.

In Ireland, wind energy is the largest contributor in terms of renewable generation in Ireland with 5.61% of gross electricity [3]. But due to the nature of micro wind and the locations such units are likely to be installed, i.e. urban environments, considerations including the technology potential, the site, proximity to potential obstacles etc. all serve to cloud the perspective on the viability and potential that could be harnessed. A consensus on the range of technologies currently available in Ireland is lacking and there is increasing research into the potential that these technologies can offer.

Small wind energy systems are generally not considered to be cost effective at present and indeed the Energy Savings Trust (EST) study [10] suggests that the technology will need to be supported until it reaches its cost effectiveness.

IV. Potential Drivers

The recent government White Paper [12] outlined a target of generating 33% of electricity requirements from renewable sources by 2020 will be assisted by the greater use of micro-renewable technologies such as wind, solar, heat pumps and biomass. To encourage the uptake of such micro-renewables, it is proposed to amend the exempted development provisions of the Planning and Development Regulations 2001. The proposed exemptions will allow for small wind turbines up to 12m in height to be erected in gardens, for solar panels up to $12m^2$ to be installed at the back or front roof of a house [13].

In terms of improving the economics of small wind turbines, areas which are likely to see short to medium improvements include:

- Reliability and energy yields
  Maturity of the technologies should assure this
- Technology positioning intelligence
  As the available quantity of (accurate) wind data grows, energy predictions will become more accurate and site installation experiences will provide the knowledge to place technologies in the locations guaranteeing maximum wind capture
- Feed-in tariff structure(s)

The UK Government and the Department for Business, Enterprise and Regulatory Reform (BERR), formally the Department of Trade and Industry (DTI), offer a range of incentives attempting to encourage and develop the sector. Indeed, in March 2006, the BERR published its micro generation Strategy to create the conditions under which micro-generation becomes a realistic alternative or supplementary energy generation source. To realise such an objective, actions on constraints pertaining to cost, information, technical development and regulatory control are required. To date progress has been made in terms of planning, export tariffs, and the development of the 'Micro-generation Certification Scheme'.

Indeed, in the UK, there is an intention for all new homes to be zero carbon by 2016 with a major progressive tightening of the energy efficiency building regulations - by 25% in 2010 and by 44% in 2013 - up to the zero carbon targets in 2016. The European position with wind generation technology was investigated via The Wind Energy Integration in the Urban Environment (Wineur) Project. This project was set up to identify the conditions that need to be established for the integration of small wind turbines into the urban environment; to promote the emergence of this technology as a real option for electricity supply in towns and cities across Europe by raising awareness amongst municipal authorities and decision makers.

In relation to the rates of adoption of renewable energies by European countries in general, there are significant differences. In early 2007, the European Commission set new binding targets for 2020 to increase the annual share of renewable energies in final energy by 20%. This implies a 34% target for electricity from renewable resources from the current 15% The new EU target translates into national targets. The target for Ireland is 16% of final energy which presents a significant challenge.

In the Irish context, Government plans to encourage businesses and individual householders to generate their own electricity using wind and solar power under a trial programme. The 'micro-generation' programme allowed the potential to sell excess power back to the National Grid.

A 50 per cent start-up grant will be made available to cover the installation costs of micro-generation systems in about 50 trials to be conducted throughout the State. €2 million will be provided by the department in 2008 to fund the grant scheme, which will be administered by SEI, the national energy agency and other bodies such as the Commission for Energy Regulation and ESB Networks.

V. TECHNICAL ASPECTS OF MICRO GENERATION INTEGRATION

In a report commission by SEI investigating the costs and benefits of embedded generation [4] an addendum focused on micro-generation. This addendum outlined a model that was representative of the Irish Distribution Network. This work was in the context of an earlier work [14] that provided more specific detail for the UK context and specifically how it would absorb increasing levels of micro-generation.

A similar model has been developed (Fig. 1) to initially investigate the claims that the Irish Distribution Network could not safely accommodate micro-generation in excess of 40% of substation capacity as outlined in [7]. This model is compiled in Excel and uses MATLAB© to implement a Distflow routine as outlined in [15] to evaluate the Load Flow solution of the modeled network under varying load/generation scenarios.

The Representative Irish Network is comprised of:

- One 500MVA Source
- Two 10 MVA Transformer (YY0, 38/10.5kV)
- Five, 10kV Distribution feeders with one modeled in detail
    - This feeder is 3km long with 1.5km being 185mm^2 10kV PICAS and the remaining 1.5km being of 95 mm^2, 10kV PICAS
  - The detailed feeder contains ten 10/0.433kV Substations, each substation having four LV feeders.
  - One of the LV Feeders is modeled in detail
    - This feeder is 300m long with 150m being 185mm^2 415V CNE and the remaining 150 being of 95mm2, CNE.

The representative Irish Network is modelled as having 43 busses which for the sake of the Distflow algorithm are divided into 20 'laterals'.

The methodology involved in the algorithm is to:

- Recursively evaluate the voltage for each bus assuming no losses for the initial sweep through the system
- Use the derived bus voltages to evaluate the power flows:
- Evaluate losses
- Re-evaluate bus voltages
- Repeat process until convergence is achieved.

Distflow was employed as the optimal methodology to derive the load flow results of the network being considered as standard load flow approaches have difficulties in converging given the challenges posed by distribution networks – specifically the high X/R ratios.

The *Distflow* Equations are derived in terms of Fig. 2.

$$P_{(i)} = P_{(i-1)} - P_{(loss)}; \qquad Q_{(i)} = Q_{(i-1)} - Q_{(loss)} \tag{4}$$

$$P_{(loss)} = \frac{P_{(i)}^{2} + Q_{(i)}^{2}}{V_{(i)}} \times r; \qquad Q_{(loss)} = \frac{P_{(i)}^{2} + Q_{(i)}^{2}}{V_{(i)}} \times r \tag{5}$$

$$V_{(i)} = \sqrt{\left\{ \left[\frac{2.(P_{(i)}^{2}.r_{(i-1)} + Q_{(i)}^{2}.x_{(i-1)}) - V_{(i)}^{2}}{2} \right] + \left[\frac{\left[2.(P_{(i)}.r_{(i-1)} + Q_{(i)}.x_{(i-1)}) - V_{(i)}^{2}\right] - 4\left[(P_{(i)}^{2} + Q_{(i)}^{2}).(r_{(i)}^{2} + x_{(i)}^{2})\right]}{2} \right] \right\}} \tag{6}$$

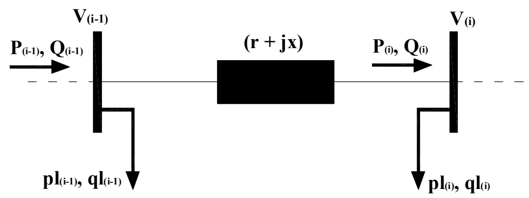

Fig 2. Radial Feeder

The Power Flow for the system was derived using the algorithm described in [15]:

$$P_{(i)} = TP_{(L)} - PS_{(L)} - SPL_{(L)} \tag{7}$$

where

$P_{(i)}$ is the power flowing into the specific bus being evaluated

$TP_{(L)}$ is the total power flowing into the specific lateral containing the bus being investigated

$PS_{(L)}$ is the total power of associated laterals connected to the specific lateral prior to the bus being investigated

$SPL_{(L)}$ is the actual load and associated losses attributable to branches prior to the bus in question.

The model developed was flexible so as to satisfy ranging scenarios (as suggested in [18]) but initially, an investigation into the following scenarios was presented:

- Maximum Demand on each substation (of each 10kV feeder), 0% Generation
- Minimum Demand on each substation (of each 10kV feeder), 0% Generation
- Minimum Demand on each substation (of each 10kV feeder), 100% Generation

Each substation, serves 312 customers (over three phases) and each customer is modeled as having an ADMD of 1.28kVA and the potential of affording a micro-generation technology with capacity of 1.1kVA. Each substation was modeled with a load factor of 50%.

The results of the different load/generation secenarios are illustrated in Fig. 3 where the voltage profiles for the different load/generation scenarios are graphically portrayed. The auto-tapping of the MV distribution transformer is evident in maintaining the voltage profile within network constraints when additional generation is added, whilst assisting to boost the voltage level when the system is loaded.

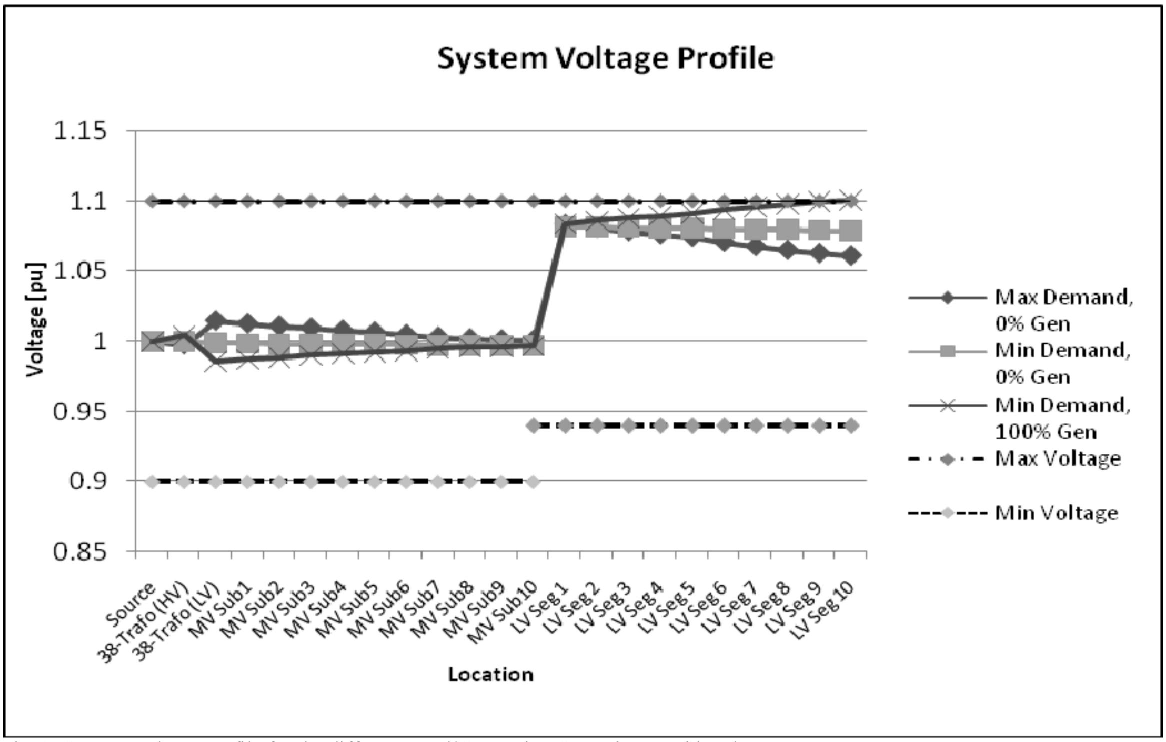

Fig. 3: System Voltage Profile for the different Load/Generation Scenarios considered.

VI. CONCLUSIONS

A detailed perspective on the status of micro-generation has been presented with the position of the Irish Regulator defined [7,8].

In particular, the suggestion that the level of micro-generation integration should be curtailed to a penetration level up to 40% has been investigated. This was achieved by compiling a model, as described in [4,10] and through implementation of the *Distflow* methodology described in [15] the basis of this limitation has been been analysed.

The justification for limiting the integration of increasing levels of micro-generation into Irish Distribution Network is to protect against the inherent voltage rise associated with increasing the level of embedded generation. However, the results shown in Fig. 3 suggest that the modeled representative Irish Network can accept almost 100% of customers with 1.1kVA micro-generation at minimum load of 0.16kVA per customer (which is considered a pessimistic loading level) without exceeding the maximum voltage excess of +10%. This is achieved with the MV transformers on auto-tap whilst the sub station transformers with fixed at positions. Indeed, if tapping of the substation transformers was a possibility, one could speculate that higher level micro-generation penetration can be facilitated.

The work presented forms the basis of a series of investigations on the viability of micro-generation with further work being developed to investigate how the micro-wind characteristics associated micro-generation technologies impact on penetration levels in terms of their positioning and capabilities.

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